Heavy Top Quark Production in the Bestest Little Higgs Model at the LHC

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Outline

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  - Motivation
  - Scalar Sector
  - Gauge Sector
  - Fermion Sector
- Heavy Top Quark Production
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- Conclusions

The Bestest Little Higgs Model

Schmaltz, Stolarski, Thaler (2010), hep-ph/1006.1356v1

- Difficult to generate Higgs quartic coupling that preserves custodial SU(2) symmetry in LH models

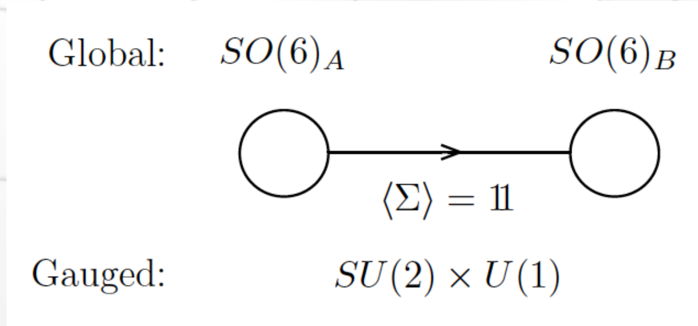
- Most LH models predict $\dfrac{m_T}{m_{W'}} \simeq \dfrac{m_t}{m_W} \simeq 2$
  - Precision EW physics constrain heavy gauge boson masses $m_{W'} \gtrsim 2-3\ \mathrm{TeV}$
  - Avoiding fine-tuning in the top sector requires $m_T \lesssim 1\text{–}2\ \mathrm{TeV}$

- Bestest LH Model generates a custodially symmetric Higgs quartic coupling with relatively light top partners

Collective Quartic Coupling

- $SO(6)_A \times SO(6)_B \rightarrow SO(6)$

$$\Sigma = e^{i\Pi/f} e^{2i\Pi_h/f} e^{i\Pi/f}$$



- 15 scalars:
  - 2 complex Higgs doublets (4 d.o.f. each) : h_1, h_2
  - $SU(2)_L$ triplet: ϕ
  - $SU(2)_R$ triplet: η
  - Real singlet: σ

$$\Pi_h = \frac{i}{\sqrt{2}} \begin{pmatrix} 0_4 & h_1 & h_2 \\ -h_1^T & 0 & 0 \\ -h_2^T & 0 & 0 \end{pmatrix} \qquad \Pi = i \begin{pmatrix} \phi_a T_L^a + \eta_a T_R^a & 0 & 0 \\ 0 & 0 & \sigma/\sqrt{2} \\ 0 & -\sigma/\sqrt{2} & 0 \end{pmatrix}$$

$$V_{\text{quartic}} = \frac{\lambda_{65}}{2}\left(f\,\sigma - \frac{1}{\sqrt{2}} h_1^T h_2 + \dots\right)^2 + \frac{\lambda_{56}}{2}\left(f\,\sigma + \frac{1}{\sqrt{2}} h_1^T h_2 + \dots\right)^2$$

- Integrating out σ gives:

$$V_{\text{quartic}} = \frac{\lambda_{56}\lambda_{65}}{\lambda_{65}+\lambda_{56}} \left(h_1^T h_2\right)^2 = \frac{1}{2}\lambda_0 \left(h_1^T h_2\right)^2$$

Scalar Potential and EWSB

- Scalar Potential below $f \sim 1$ TeV:

$$V_{\text{higgs}} = \frac{1}{2} m_1^2 \, h_1^T h_1 + \frac{1}{2} \, m_2^2 h_2^T h_2 - B_\mu \, h_1^T h_2 + \frac{\lambda_0}{2} (h_1^T h_2)^2$$

- EWSB: $\tan\beta \equiv \frac{\langle h_{11} \rangle}{\langle h_{21} \rangle} = \frac{m_2}{m_1}$

$$v_{\text{EW}}^2 \equiv \langle h_{11} \rangle^2 + \langle h_{21} \rangle^2 = \frac{1}{\lambda_0} \left(\frac{m_1^2 + m_2^2}{m_1 m_2} \right) (B_\mu - m_1 m_2) \simeq (246\,\text{GeV})^2$$

- Higgs spectrum below f is a 2HDM

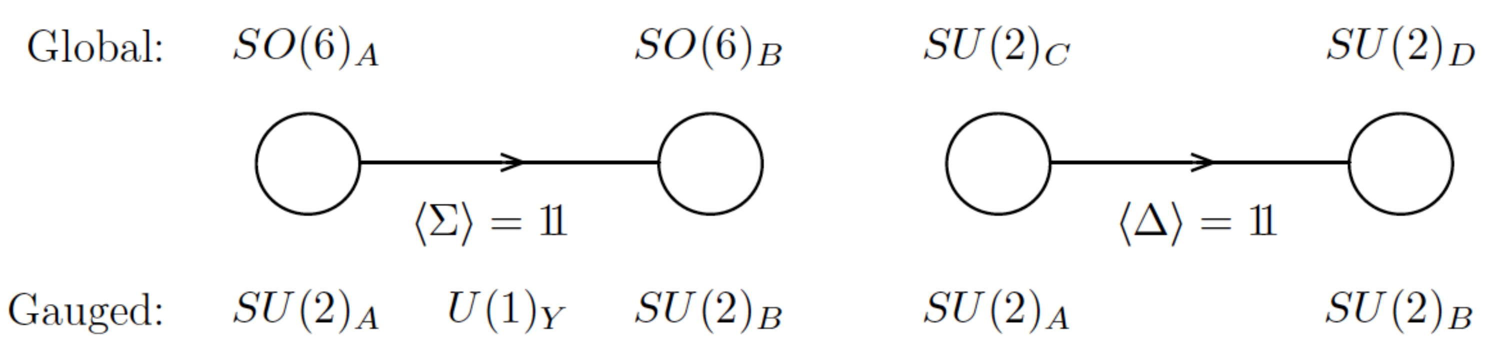
$$M_{h^0, H^0}^2 = \frac{B_\mu}{\sin 2\beta} \mp \sqrt{\frac{B_\mu^2}{\sin^2 2\beta} - 2\lambda_0 B_\mu \, v^2 \sin 2\beta + \lambda_0^2 \, v^4 \sin^2 2\beta}$$

$$M_{A^0}^2 = M_{H^\pm}^2 = m_1^2 + m_2^2 = \frac{2\, B_\mu}{\sin 2\beta} - \lambda_0 v^2$$

$$M_{h^0}^2 < M_{A^0}^2 \approx M_{H^\pm}^2 < M_{H^0}^2$$

Gauge Sector

- Introduce another independent sigma model at a scale $F > f$



$$\Sigma = e^{i\Pi/f} e^{2i\Pi_h/f} e^{i\Pi/f} \qquad \Delta = e^{2i\Pi_d/F}, \qquad \Pi_d = \chi_a \frac{\tau^a}{2}$$

- Σ breaks $SO(6)_A \times SO(6)_B$ to diagonal subgroup at scale f
- Δ breaks $SU(2)_C \times SU(2)_D$ to diagonal subgroup at scale F

$$\mathcal{L} = \frac{f^2}{8}\mathrm{tr}\left(D_\mu\Sigma^\dagger D^\mu\Sigma\right) + \frac{F^2}{4}\mathrm{tr}\left(D_\mu\Delta^\dagger D^\mu\Delta\right) \qquad A_i^{(6)} = A_i^a T^a, \qquad A_i^{(2)} = A_i^a \frac{\tau^a}{2}$$

$$D\Sigma = \partial\Sigma + ig_A A_1^{(6)}\Sigma - ig_B\Sigma\, A_2^{(6)}, \qquad D\Delta = \partial\Delta + ig_A A_1^{(2)}\Delta - ig_B\Delta\, A_2^{(2)}$$

Gauge Boson Masses

- After EWSB, the gauge boson masses become:

$$M_\gamma^2 = 0$$

$$M_Z^2 = \frac{1}{4}\left(g^2+g'^2\right)v^2 - \left(g^2+g'^2\right)\left(2+\frac{3f^2}{f^2+F^2}\left(s_g^2-c_g^2\right)^2\right)\frac{v^4}{48f^2}$$

$$M_W^2 = \frac{1}{4}g^2v^2 - g^2\left(2+\frac{3f^2}{f^2+F^2}\left(s_g^2-c_g^2\right)^2\right)\frac{v^4}{48f^2}$$

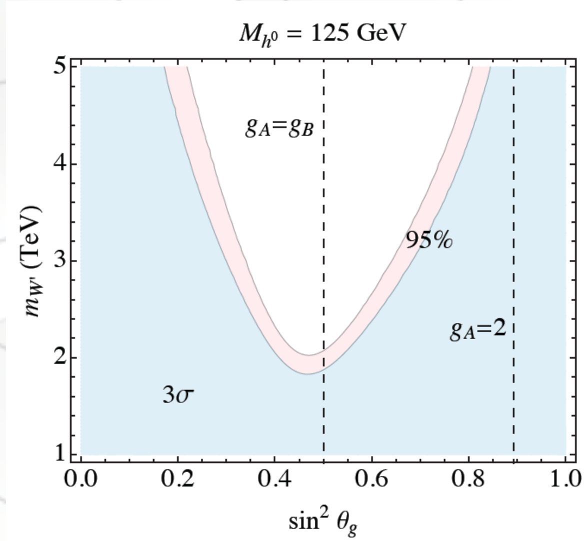
$$M_{Z'}^2 = \frac{1}{4}\left(g_A^2+g_B^2\right)\left(f^2+F^2\right) - \frac{1}{4}g^2v^2 + \left(2g^2+\frac{3f^2}{f^2+F^2}\left(g^2+g'^2\right)\left(s_g^2-c_g^2\right)^2\right)\frac{v^4}{48f^2}$$

$$M_{W'}^2 = \frac{1}{4}\left(g_A^2+g_B^2\right)\left(f^2+F^2\right) - M_W^2$$

- $\rho = 1$ at $O(v^4/f^2)$

- Heavy Gauge Boson masses $\sim F > f$

- We choose $\tan\theta_g \equiv g_A/g_B = 1$



Fermion Sector

- To build Yukawa interactions, Fermions must transform under $SO(6)_A$ or $SO(6)_B$

$SO(6)_A$: $$Q^T = \left(\tfrac{1}{\sqrt{2}}(-Q_{a1} - Q_{b2}) \quad \tfrac{i}{\sqrt{2}}(Q_{a1} - Q_{b2}) \quad \tfrac{1}{\sqrt{2}}(Q_{a2} - Q_{b1}) \quad \tfrac{i}{\sqrt{2}}(Q_{a2} + Q_{b1}) \quad Q_5 \quad Q_6 \right)$$

$SO(6)_B$: $$(U^c)^T = \left(\tfrac{1}{\sqrt{2}}(-U^c_{b1} - U^c_{a2}) \quad \tfrac{i}{\sqrt{2}}(U^c_{b1} - U^c_{a2}) \quad \tfrac{1}{\sqrt{2}}(U^c_{b2} - U^c_{a1}) \quad \tfrac{i}{\sqrt{2}}(U^c_{b2} + U^c_{a1}) \quad U^c_5 \quad U^c_6 \right)$$

$SU(2)_A$ doublet: $${Q'_a}^T \rightarrow \tfrac{1}{\sqrt{2}}(-Q'_{a1}, iQ'_{a1}, Q'_{a2}, iQ'_{a2}, 0, 0)$$

$SU(2)_B$ singlet: $$U_5'^{cT} \rightarrow (0, 0, 0, 0, U_5'^c, 0)$$

$$S = \mathrm{diag}(1, 1, 1, 1, -1, -1)$$

$$\mathcal{L}_t = \underbrace{y_1 f\, Q^T S \Sigma S U^c}_{\text{Breaks } SO(6)_A \,\&\, SO(6)_B} + \underbrace{y_2 f\, {Q'_a}^T \Sigma U^c}_{\text{Preserves } SO(6)_B} + \underbrace{y_3 f\, Q^T \Sigma U_5'^c}_{\text{Preserves } SO(6)_A} + \text{ h.c.}$$

- All 3 terms collectively break the symmetries protecting the Higgs
  $\therefore$ Top Yukawa & radiative corrections to V_{higgs} can be generated

Heavy Top Quark Masses

- After EWSB, the fermion masses become (assuming $y_2 \neq y_3$):

$$M_t^2 = y_t^2 v_1^2 \quad \text{where} \quad y_t^2 = \frac{9y_1^2 y_2^2 y_3^2}{(y_1^2+y_2^2)(y_1^2+y_3^2)}$$

$$M_{T_{au}}^2 = \left(y_1^2 + y_2^2\right) f^2 + \frac{9v_1^2 y_1^2 y_2^2 y_3^2}{(y_1^2+y_2^2)(y_2^2-y_3^2)}$$

$$M_{T_{ad}}^2 = \left(y_1^2 + y_2^2\right) f^2$$

$$M_{T_5}^2 = \left(y_1^2 + y_3^2\right) f^2 - \frac{9v_1^2 y_1^2 y_2^2 y_3^2}{(y_1^2+y_3^2)(y_2^2-y_3^2)}$$

$$M_{T_6}^2 = M_{T_{b2}}^2 = M_{T_{b5}}^2 = y_1^2 f^2$$

Charge 2/3: T_{au}, T_{b2}, T_5, T_6

Charge -1/3: T_{ad}

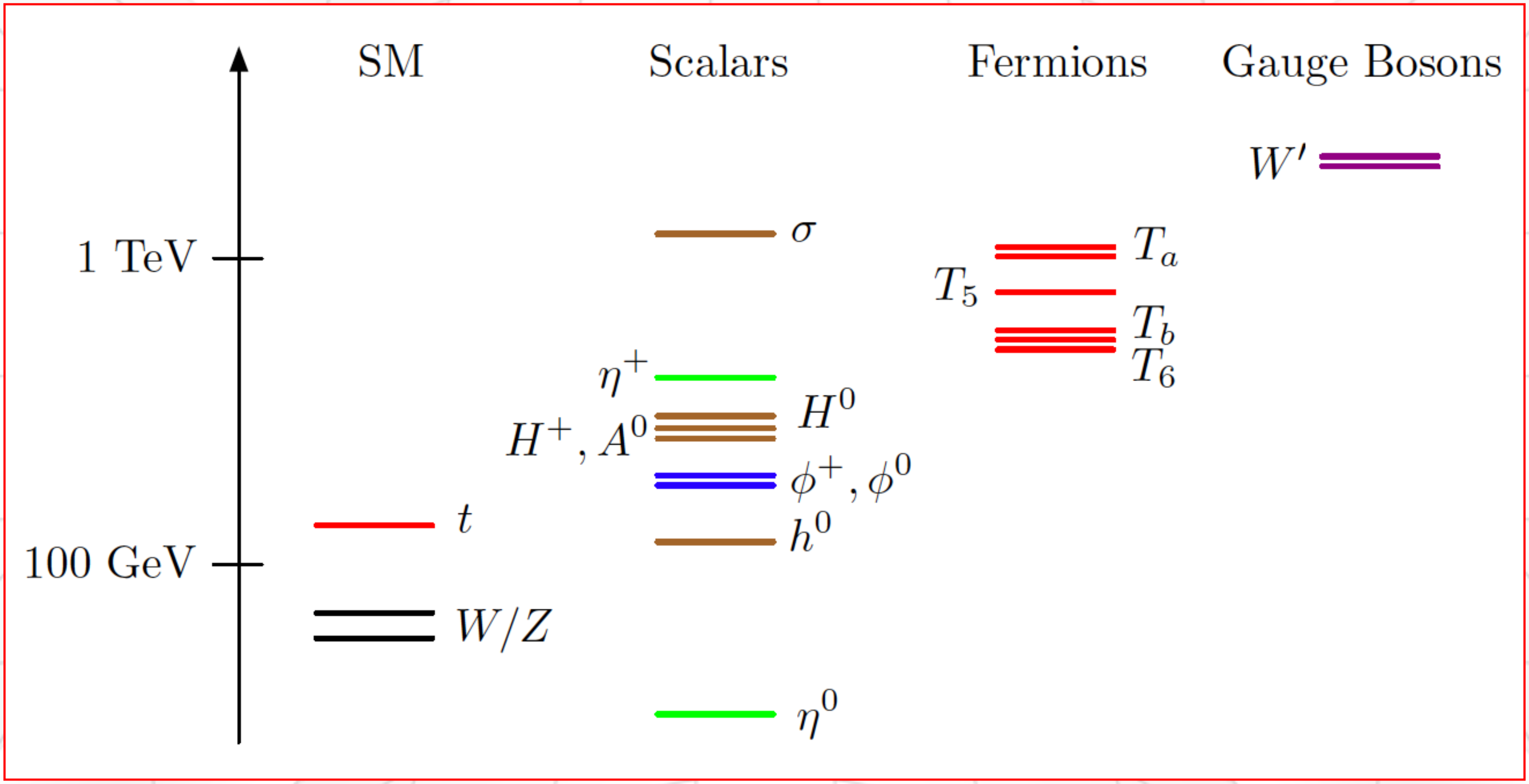
Charge 5/3: T_{b5}

- Heavy Top Masses ~ $f < F$, lighter than Heavy Gauge Bosons

$$M_{Z'}^2 = \tfrac{1}{4}\left(g_A^2 + g_B^2\right)\left(f^2 + F^2\right) - \tfrac{1}{4} g^2 v^2 + \left(2g^2 + \tfrac{3f^2}{f^2+F^2}\left(g^2 + g'^2\right)\left(s_g^2 - c_g^2\right)^2\right)\frac{v^4}{48 f^2}$$

$$M_{W'}^2 = \tfrac{1}{4}\left(g_A^2 + g_B^2\right)\left(f^2 + F^2\right) - M_W^2$$

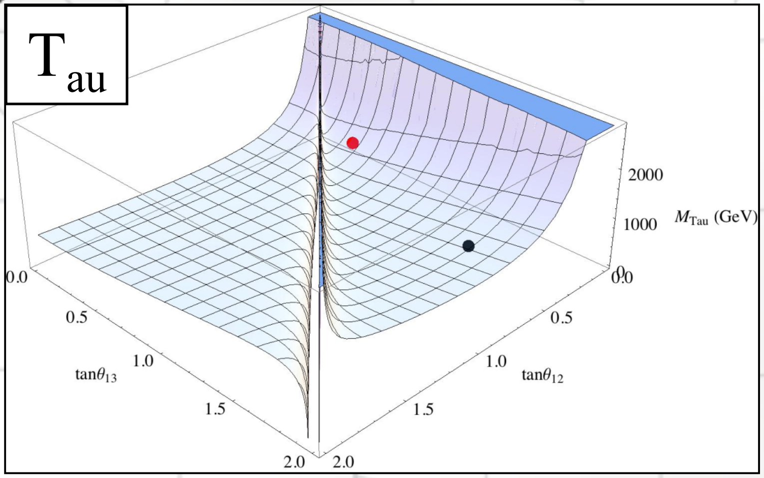
Particle Spectrum



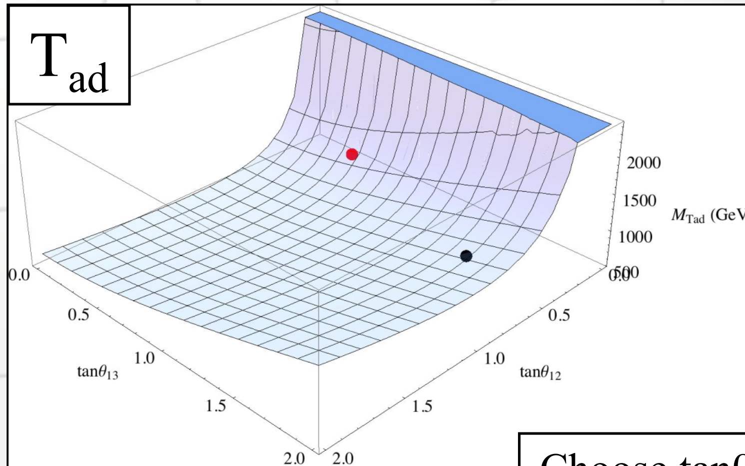
- Note: Top partners are relatively light (required to avoid fine-tuning)

Heavy Top Masses - Dependence on Mixing Angles

T_{au}



T_{ad}



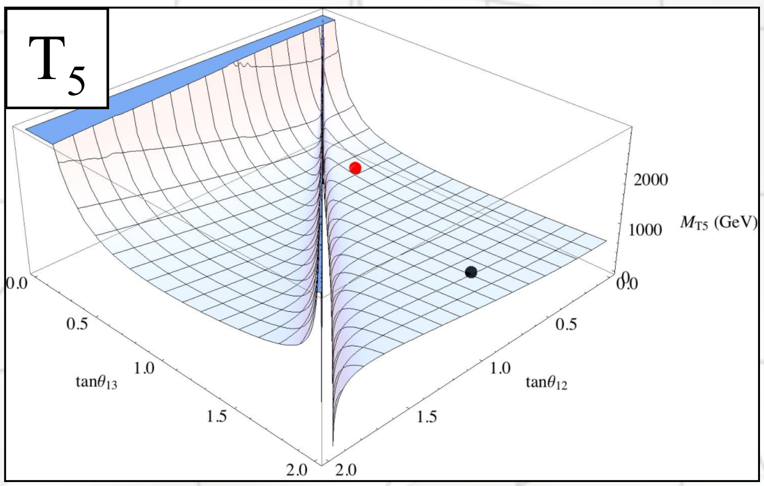
$\tan\theta_{12} \equiv y_1/y_2$

$\tan\theta_{13} \equiv y_1/y_3$

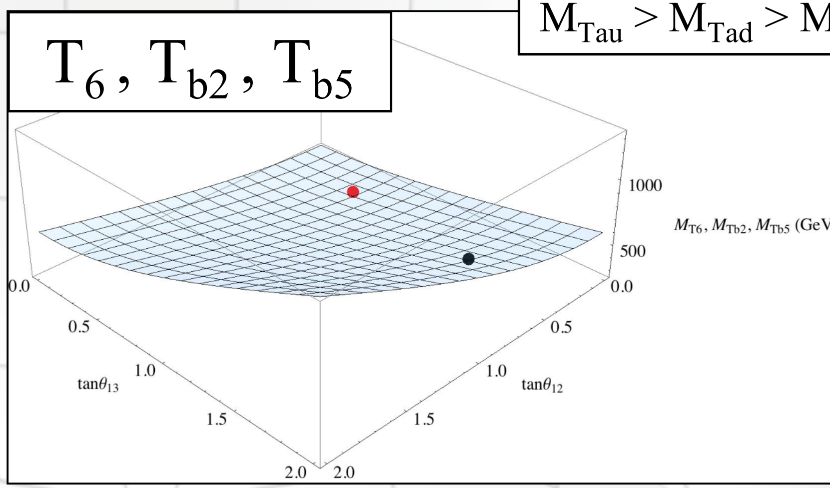
$\tan\beta = \sqrt{3}$
$f = 1$ TeV
$M_t = 172.0$ GeV

Choose $\tan\theta_{13} > \tan\theta_{12}$ so that $M_{Tau} > M_{Tad} > M_{T5} > M_{T6}$

T_5



T_6 , T_{b2} , T_{b5}



- ● $(\tan\theta_{12}, \tan\theta_{13}) = (0.727, 1.732)$
- ● $(\tan\theta_{12}, \tan\theta_{13}) = (0.325, 0.577)$

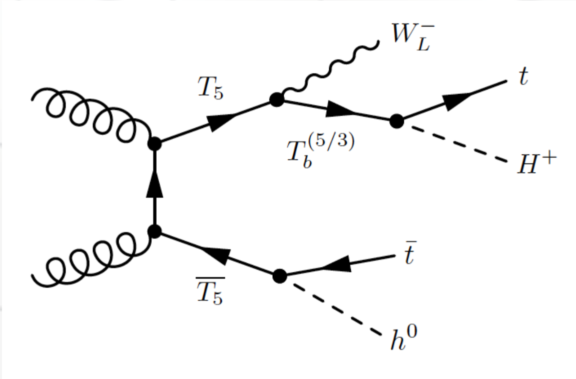
Heavy Top Branching Ratios

$(\tan\theta_{12}, \tan\theta_{13})$	• (0.727, 1.732)	• (0.325, 0.577)
Fermion Masses (GeV)		
M_{Tau}	1,142	1,065
M_{Tad}	1,131	1,056
M_{T5}	731	615
$M_{T6} = M_{Tb2} = M_{Tb5}$	665	326
Dominant T_5 Decay Modes (M_h = 120 GeV)	$BR(T_5 \to b\,W^+) = 0.480$ $BR(T_5 \to t\,Z) = 0.225$ $BR(T_5 \to t\,h) = 0.114$	$BR(T_5 \to T_{b2}\,h) = 0.420$ $BR(T_5 \to T_{b5}\,W^-) = 0.269$ $BR(T_5 \to T_{b2}\,Z) = 0.131$ $BR(T_5 \to T_6\,h) = 0.116$

- $\tan\beta = \sqrt{3}$, M_t = 172.0 GeV, f = 1 TeV
- Benchmark Point: $(\tan\theta_{12}, \tan\theta_{13})$ = (0.727, 1.732) for shorter decay chains

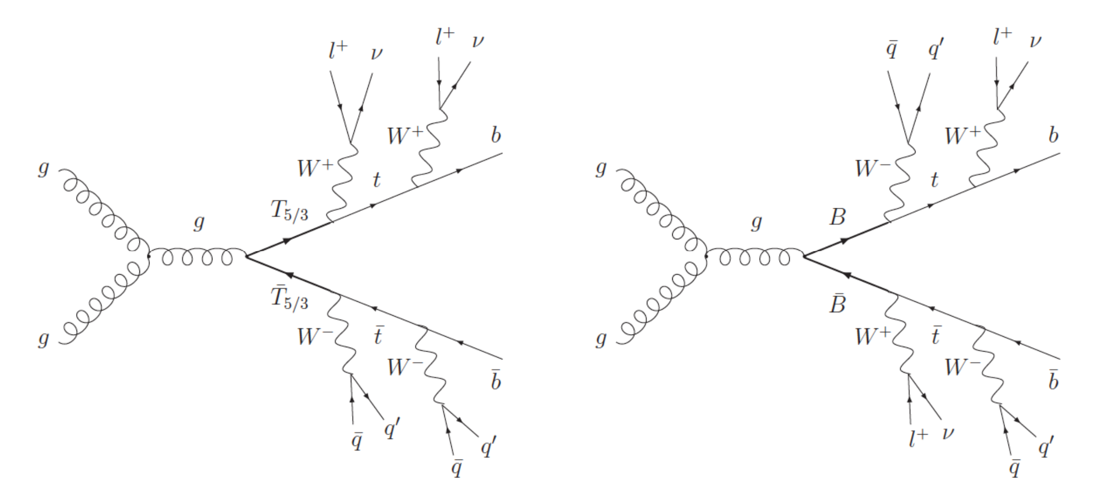
Heavy Top Pair Production

- Pair Production occurs via gluon fusion



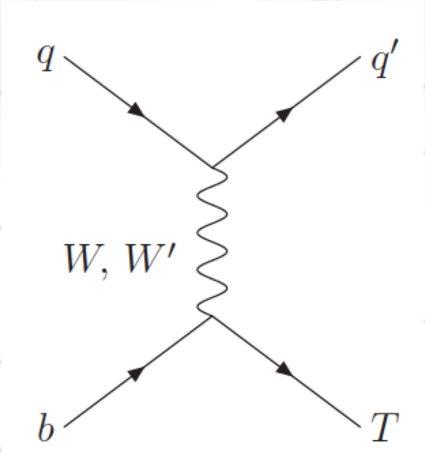
- Cascade decays lead to many particles in the final state

- Pair Production of charge 5/3 and -1/3 heavy quarks leads to same sign dileptons (Contino, Servant, hep-ph/0801.1679v2)

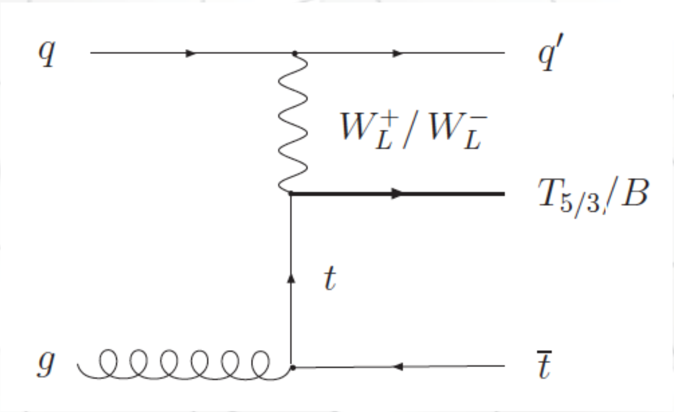


Heavy Top Single Production

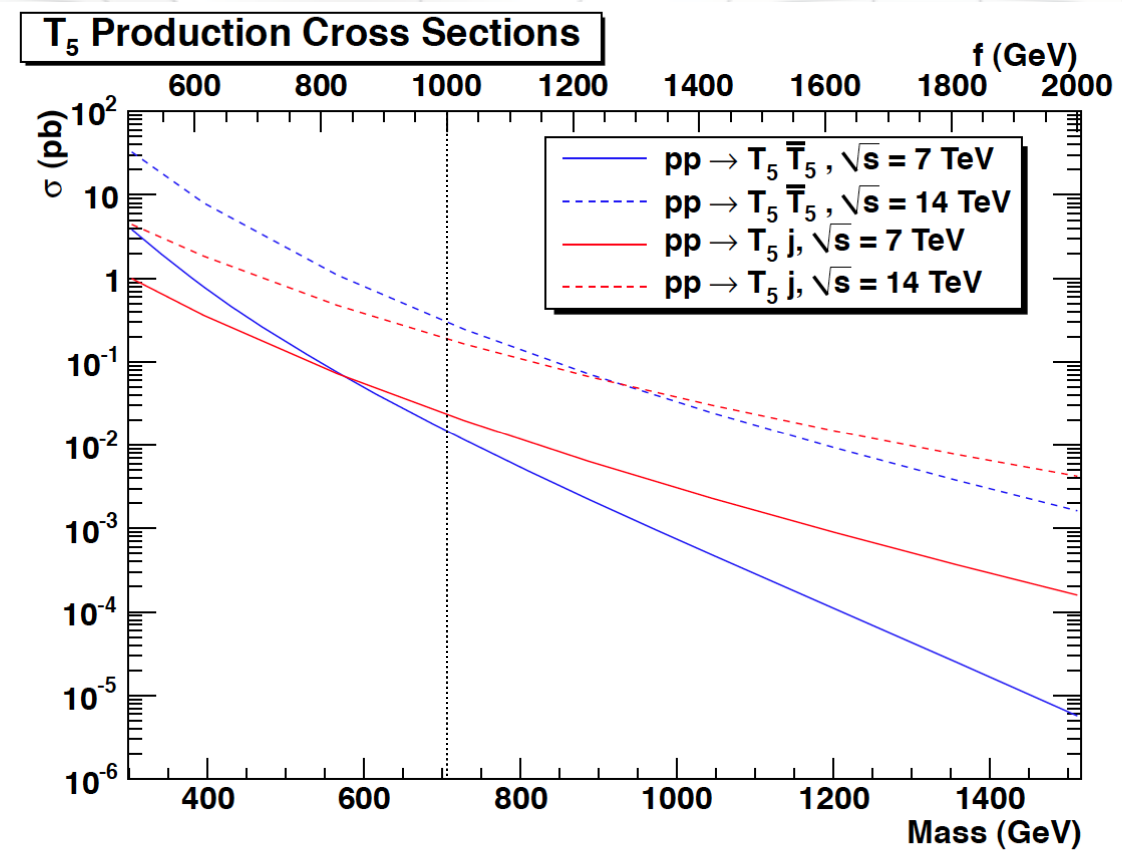
- Single production of charge 2/3 heavy quarks occurs via W exchange between light quark and b-quark partons



- Single production of charge 5/3 and -1/3 quarks occurs in association with a top quark



T_5 Production



Process (f = 1 TeV)	σ (fb), 7 TeV	σ (fb), 14 TeV
Pair Production	11.555	244.98
Single Production	19.670	163.57

BRs for f = 1 TeV, $(\tan\theta_{12}, \tan\theta_{13})$ = (0.727, 1.732)

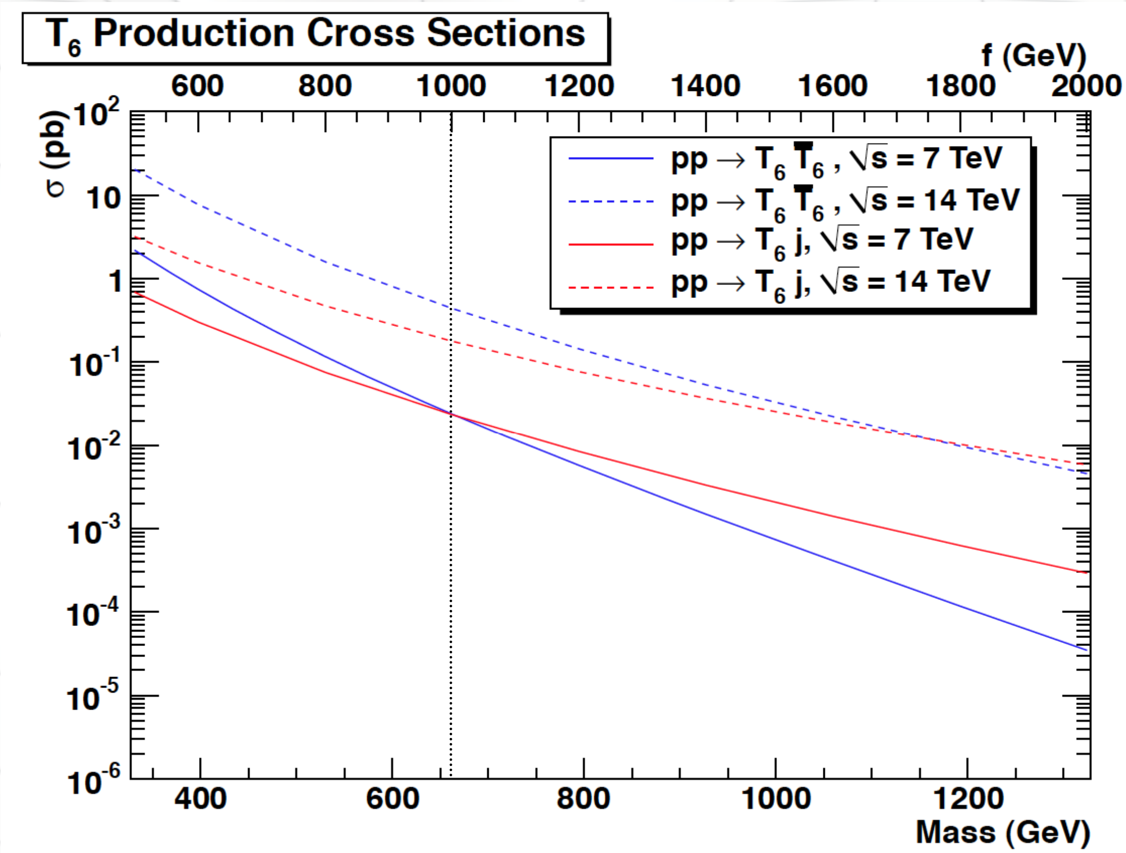
Decay Mode	BR
$T_5 \to b\, W^+$	0.480
$T_5 \to t\, Z$	0.225
$T_5 \to t\, h$	0.114
$T_5 \to b\, H^+$	0.086
$T_5 \to t\, A^0$	0.068
$T_5 \to t\, H^0$	0.018
$T_5 \to$ other	0.009

- σ calculated using MadGraph 5
- BRs calculated using BRIDGE

$$M_h = 120\text{ GeV}, \quad M_{H^0} = 505\text{ GeV}$$

$$M_{H^\pm} = M_{A^0} = 500\text{ GeV}$$

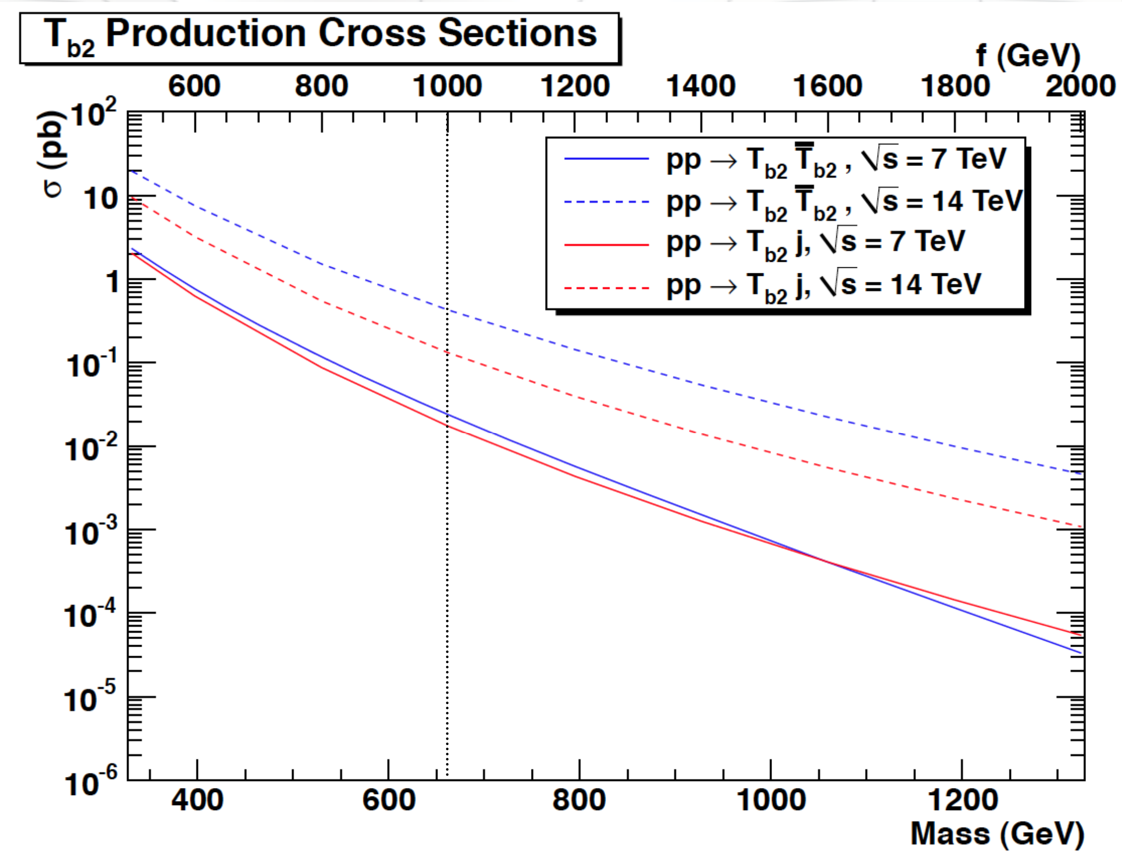
T_6 Production



Process (f = 1 TeV)	σ (fb), 7 TeV	σ (fb), 14 TeV
Pair Production	23.862	439.82
Single Production	23.481	178.09

BRs for f = 1 TeV, $(\tan\theta_{12}, \tan\theta_{13})$ = (0.727, 1.732)	
Decay Mode	BR
$T_6 \to b\,W^+$	0.416
$T_6 \to t\,h$	0.207
$T_6 \to b\,H^+$	0.192
$T_6 \to t\,Z$	0.170
$T_6 \to$ other	0.015

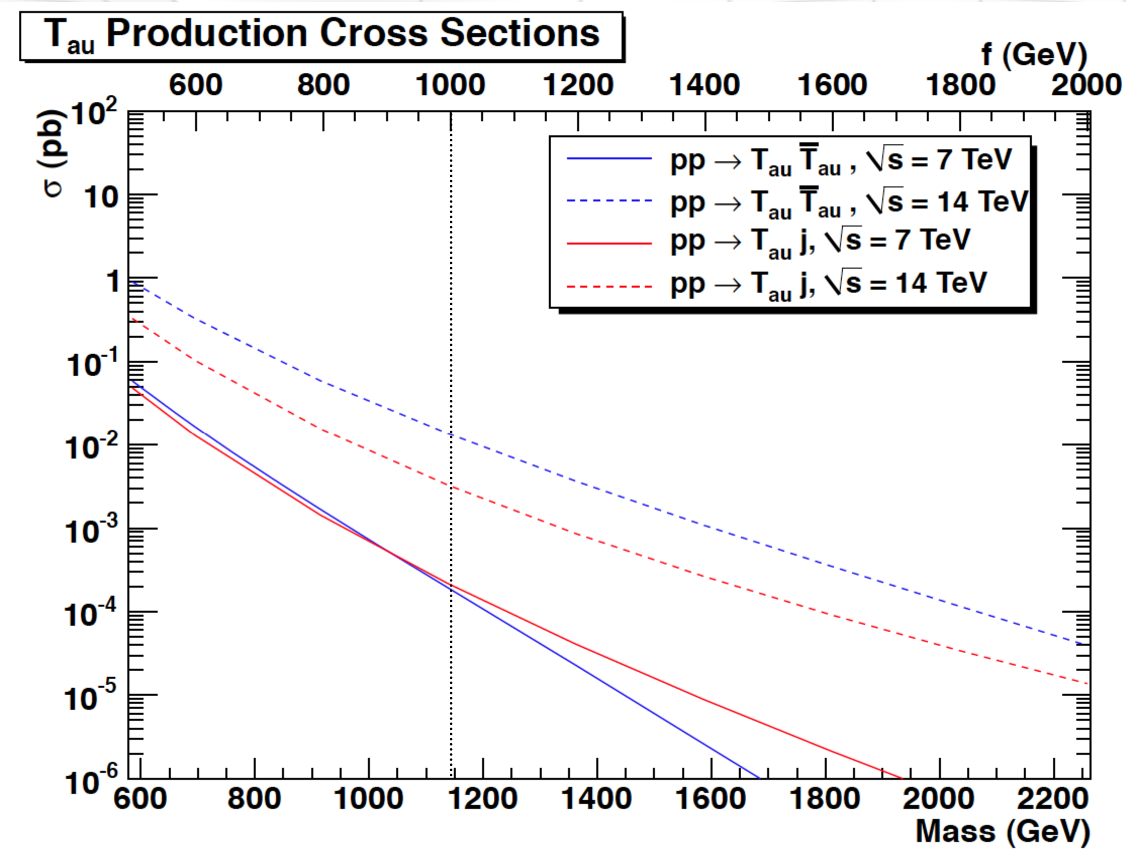
T_{b2} Production



BRs for f = 1 TeV, $(\tan\theta_{12}, \tan\theta_{13})$ = (0.727, 1.732)	
Decay Mode	BR
$T_{b2} \to t\,Z$	0.491
$T_{b2} \to b\,W^+$	0.258
$T_{b2} \to t\,h$	0.217
$T_{b2} \to b\,H^+$	0.012
$T_{b2} \to$ other	0.022

Process (f = 1 TeV)	σ (fb), 7 TeV	σ (fb), 14 TeV
Pair Production	23.982	427.67
Single Production	17.457	131.98

T_{au} Production

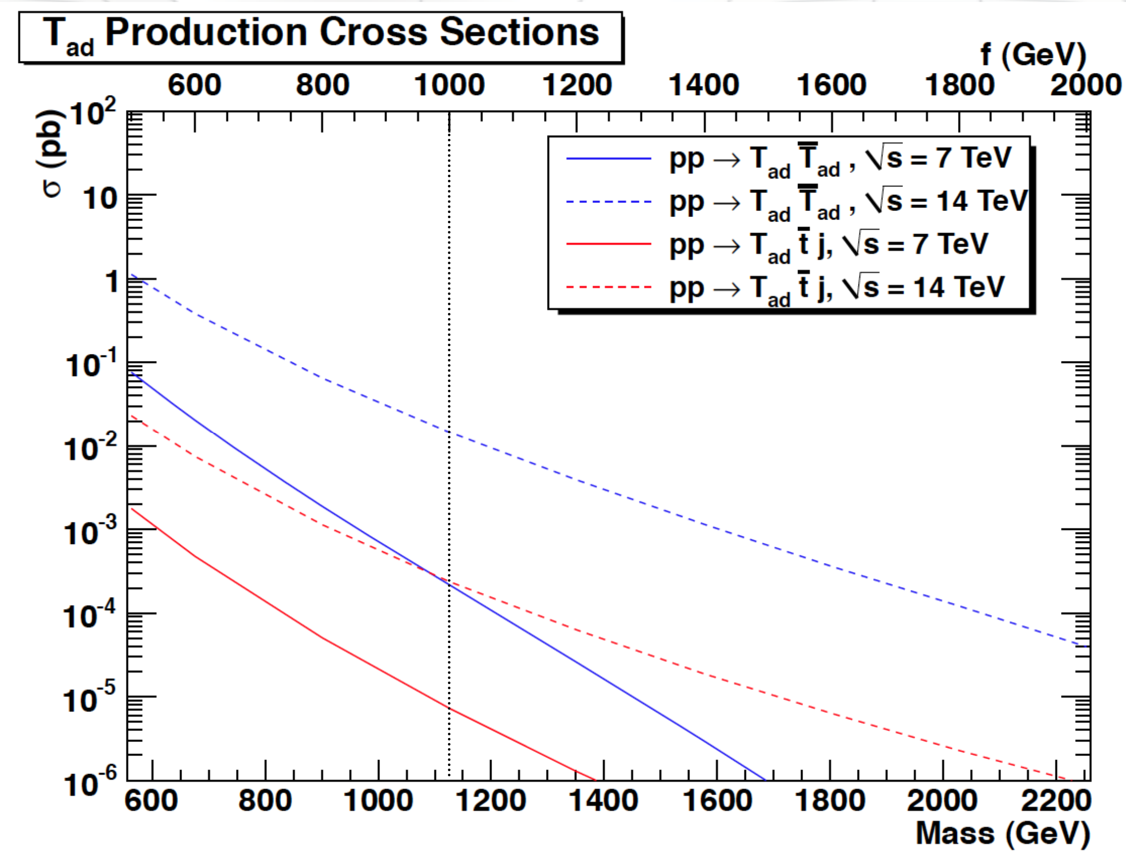


Process (f = 1 TeV)	σ (fb), 7 TeV	σ (fb), 14 TeV
Pair Production	0.19434	13.736
Single Production	0.21811	3.2883

BRs for f = 1 TeV, $(\tan\theta_{12}, \tan\theta_{13}) = (0.727, 1.732)$	
Decay Mode	BR
$T_{au} \to T_5\, Z$	0.334
$T_{au} \to T_{b2}\, Z$	0.118
$T_{au} \to T_{b2}\, h$	0.115
$T_{au} \to T_6\, Z$	0.086
$T_{au} \to T_5\, h$	0.084
$T_{au} \to T_6\, h$	0.083
$T_{au} \to t\, Z$	0.082
$T_{au} \to b\, W^+$	0.058
$T_{au} \to T_{b5}\, W^-$	0.015
$T_{au} \to$ other	0.025

Could adjust parameters so that T_{au} is lighter and more easily produced

T_{ad} Production (charge -1/3)

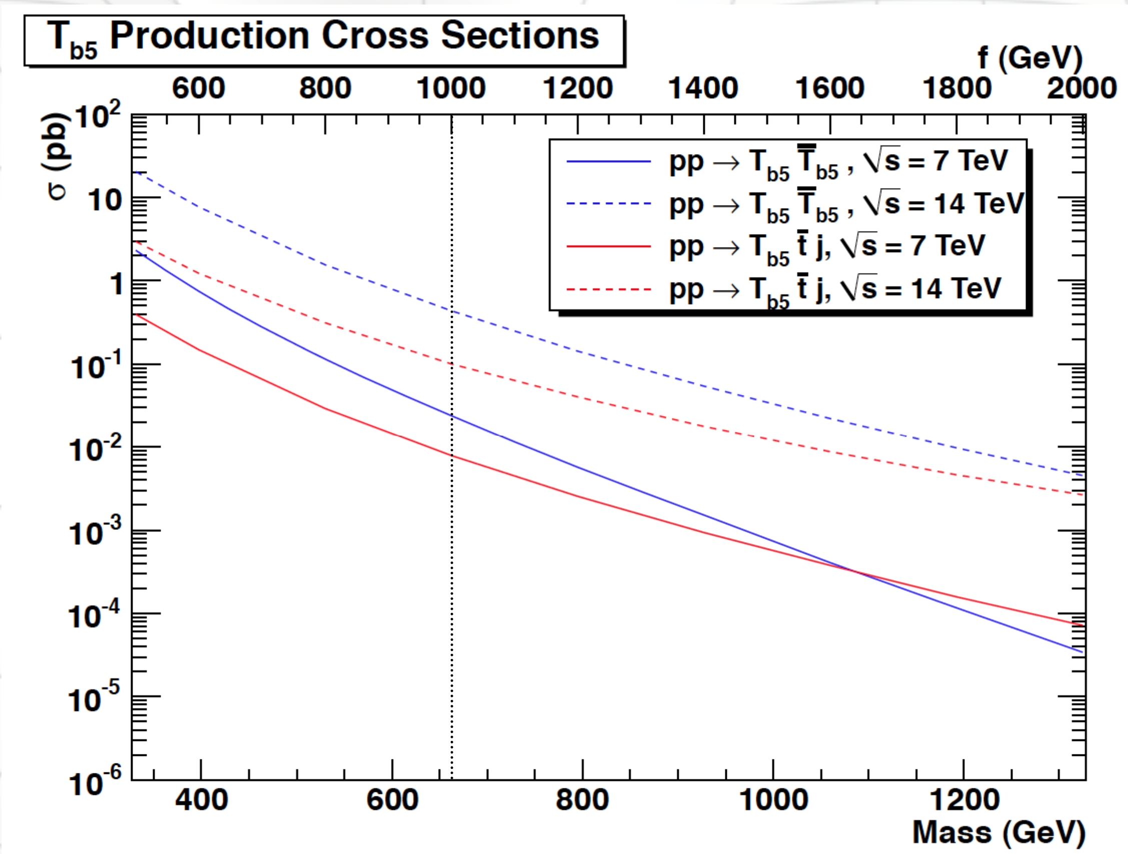


Process (f = 1 TeV)	σ (fb), 7 TeV	σ (fb), 14 TeV
Pair Production	0.21616	14.515
Single Production	0.0072314	0.23632

BRs for f = 1 TeV, $(\tan\theta_{12}, \tan\theta_{13}) = (0.727, 1.732)$	
Decay Mode	BR
$T_{ad} \to T_5\, W^-$	0.631
$T_{ad} \to T_6\, W^-$	0.164
$T_{ad} \to T_{b2}\, W^-$	0.138
$T_{ad} \to t\, W^-$	0.028
$T_{ad} \to$ other	0.039

Could adjust parameters so that T_{ad} is lighter and more easily produced

T_{b5} Production (charge 5/3)



Process (f = 1 TeV)	σ (fb), 7 TeV	σ (fb), 14 TeV
Pair Production	23.977	435.41
Single Production	7.8771	100.24

BRs for f = 1 TeV, $(\tan\theta_{12}, \tan\theta_{13})$ = (0.727, 1.732)

Decay Mode	BR
$T_{b5} \to t\, W^+$	0.982
$T_{b5} \to$ other	0.018

Conclusions & Future Work

- The Bestest Little Higgs Model generates a custodially symmetric Higgs quartic and avoids fine-tuning in the top sector
- Several top partners that are lighter than heavy gauge bosons, leading to interesting phenomenology in heavy fermion sector
- Production cross sections and branching ratios of heavy top quarks were calculated for a specific parameter set for a 7 TeV and 14 TeV LHC
- Must explore parameter space more fully and determine its effect on production cross sections and branching ratios
- Must simulate heavy top quark decays and consider backgrounds to final states

Backup Slides

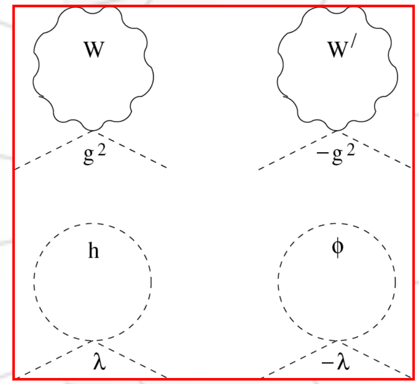
The Littlest Higgs Model

N. Arkani-Hamed et al. (2002) hep-ph/0206021

- Introduce new interactions at scale $\Lambda = 4\pi f \sim 10$ TeV with new particles at $f \sim 1$ TeV: heavy gauge bosons, heavy scalars, new heavy quarks.

- Quadratic divergences in $M_H{}^2$ are cancelled by the contributions of these new particles.

$$\delta M_H^2 = \frac{G_F \Lambda^2}{4\sqrt{2}\pi^2}\left(6M_W^2 + 3M_Z^2 + M_H^2 - 12M_t^2\right) + \ldots$$



- Scalar Sector: $h = \begin{pmatrix} h^+ \\ h^0 \end{pmatrix}$ $\phi = \begin{pmatrix} \phi^{++} & \phi^+/\sqrt{2} \\ \phi^+/\sqrt{2} & \phi^0 \end{pmatrix}$

Doublet Triplet

Littlest Higgs with Custodial SU(2)

Chang (2004) hep-ph/0306034v3

- Little Higgs Model with Left-Right Symmetry
- $SO(9) \rightarrow SO(5) \times SO(4) \supset SU(2)_L \times SU(2)_R \times SU(2)_W \times U(1)_Y$
- Scalar Sector:
  - Complex Higgs Doublet: h
  - 3 Real Triplets: ϕ^{ab} (a, b = 1, 2, 3)
  - Real Singlet: ϕ^0

$$\langle \Sigma \rangle = \begin{pmatrix} 0 & 0 & \mathbb{1}_4 \\ 0 & 1 & 0 \\ \mathbb{1}_4 & 0 & 0 \end{pmatrix}$$

$$\Sigma = e^{i\Pi/f} \langle \Sigma \rangle e^{i\Pi^T/f} = e^{2i\Pi/f} \langle \Sigma \rangle$$

$$\Pi = \frac{-i}{4} \begin{pmatrix} 0 & \sqrt{2}\vec{h} & -\Phi \\ -\sqrt{2}\vec{h}^T & 0 & \sqrt{2}\vec{h}^T \\ \Phi & -\sqrt{2}\vec{h} & 0 \end{pmatrix}$$

Littlest Higgs with Custodial SU(2)

Chang (2004) hep-ph/0306034v3

- Begin by constructing a Lagrangian:

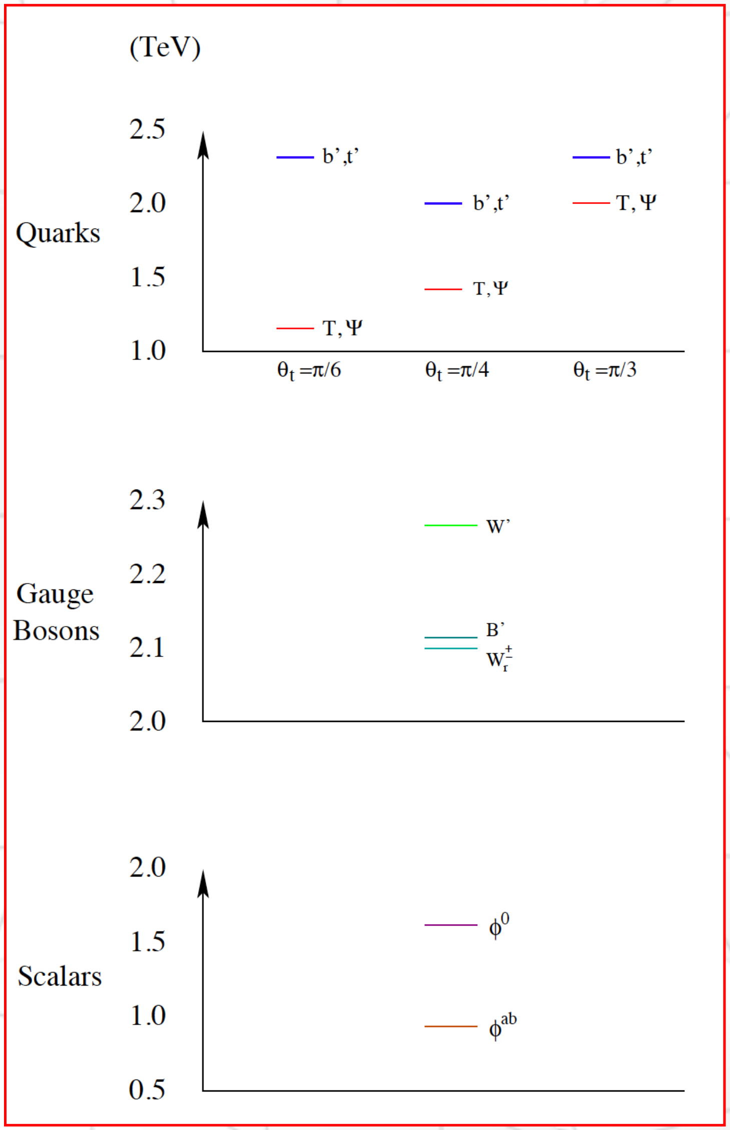
- Top Sector:

$$\mathcal{L}_{top} = y_1 f \, (\vec{\mathcal{X}}^{c\,T} \; t^c \; 0_4) \, \Sigma \begin{pmatrix} 0_5 \\ \vec{q}_t \end{pmatrix} + y_2 f \vec{\mathcal{X}}^T \vec{\mathcal{X}}^c + \text{ h.c.}$$

- Gauge Sector:

$$\mathcal{L}_{kin} = \frac{f^2}{4} \, \mathrm{Tr} \, [D_\mu \Sigma D^\mu \Sigma]$$

$$D_\mu \Sigma = \partial_\mu \Sigma + i \, [A_\mu, \Sigma]$$



Littlest Higgs with Custodial SU(2)

Chang (2004) hep-ph/0306034v3

- Radiative corrections generate a Coleman-Weinberg Potential:

$$V = \lambda_1^- f^2 (\phi^0 - H^0)^2 + \lambda_1^+ f^2 (\phi^0 + H^0)^2$$
$$+ \lambda_3^- f^2 (\phi^{ab} - H^{ab})^2 + \lambda_3^+ f^2 (\phi^{ab} + H^{ab})^2 + \Delta\lambda_3 f^2 (\phi^{a3} + H^{a3})^2 + \mu^2 h^\dagger h$$

where $\Delta\lambda_3 << \lambda_3^\pm$

- EWSB occurs when neutral scalars acquire vevs that minimize the potential

- Shift scalar fields by their vevs and determine the interactions of the theory

$h \to h + v \qquad \phi^0 \to \phi^0 + v_0 \qquad \phi^{aa} \to \phi^{aa} + v_a \;\; (v_1 = v_2 \approx v_3)$

- One can then determine mass eigenstates and calculate Feynman rules

Dangerous Singlet Problem

Schmaltz, Thaler (2009) hep-ph/0812.2477v3

- Collective Quartic:

  $V \sim \lambda_1^- f^2 (\phi^0 - H^0)^2 + \lambda_1^- f^2 (\phi^0 + H^0)^2$ where $H^0 = h^\dagger h / (4f)$

- Radiative corrections generate operators of the form:

  $- \lambda_1^- f^3 (\phi^0 - H^0 + \ldots) + \lambda_1^+ f^3 (\phi^0 + H^0 + \ldots)$

  which preserve the shift symmetries:

  $h \rightarrow h + \varepsilon + \ldots$ and $\phi^0 \rightarrow \phi^0 \pm (h^\dagger \varepsilon + \varepsilon^\dagger h)/(4f) + \ldots$

- In order to prevent quadratically divergent Higgs mass terms and ϕ^0 tadpoles at the one-loop level, additional symmetries on ϕ^0 are required.

- There is no viable one-Higgs doublet Little Higgs model where a collective quartic involves a real singlet

Fermion Sector

- To build Yukawa interactions, Fermions must transform under $SO(6)_A$ or $SO(6)_B$

$SO(6)_A$: $$Q^T = \left(\tfrac{1}{\sqrt{2}}(-Q_{a1} - Q_{b2}) \quad \tfrac{i}{\sqrt{2}}(Q_{a1} - Q_{b2}) \quad \tfrac{1}{\sqrt{2}}(Q_{a2} - Q_{b1}) \quad \tfrac{i}{\sqrt{2}}(Q_{a2} + Q_{b1}) \quad Q_5 \quad Q_6 \right)$$

$SO(6)_B$: $$(U^c)^T = \left(\tfrac{1}{\sqrt{2}}(-U^c_{b1} - U^c_{a2}) \quad \tfrac{i}{\sqrt{2}}(U^c_{b1} - U^c_{a2}) \quad \tfrac{1}{\sqrt{2}}(U^c_{b2} - U^c_{a1}) \quad \tfrac{i}{\sqrt{2}}(U^c_{b2} + U^c_{a1}) \quad U^c_5 \quad U^c_6 \right)$$

$SU(2)_A$ doublet: $Q_a'^{T} \to \frac{1}{\sqrt{2}}(-Q'_{a1}, iQ'_{a1}, Q'_{a2}, iQ'_{a2}, 0, 0)$

$SU(2)_B$ singlet: $U_5'^{cT} \to (0,0,0,0,U_5'^{c},0)$

$$S = \mathrm{diag}(1,1,1,1,-1,-1)$$

Identifying Q_a with SM quark doublet (Y=1/6) requires additional U(1) symmetry

$$T_Y = T_R^3 + T_X$$

	$SO(6)_A$	$SO(6)_B$	$SU(3)_C$	$U(1)_X$
Q	$\mathbf{6}$	$-$	$\mathbf{3}$	$2/3$
Q'_a	$\mathbf{2}^{(*)}$	$-$	$\mathbf{3}$	$2/3$
U^c	$-$	$\mathbf{6}$	$\bar{\mathbf{3}}$	$-2/3$
$U_5'^c$	$-$	$\mathbf{1}^{(*)}$	$\bar{\mathbf{3}}$	$-2/3$